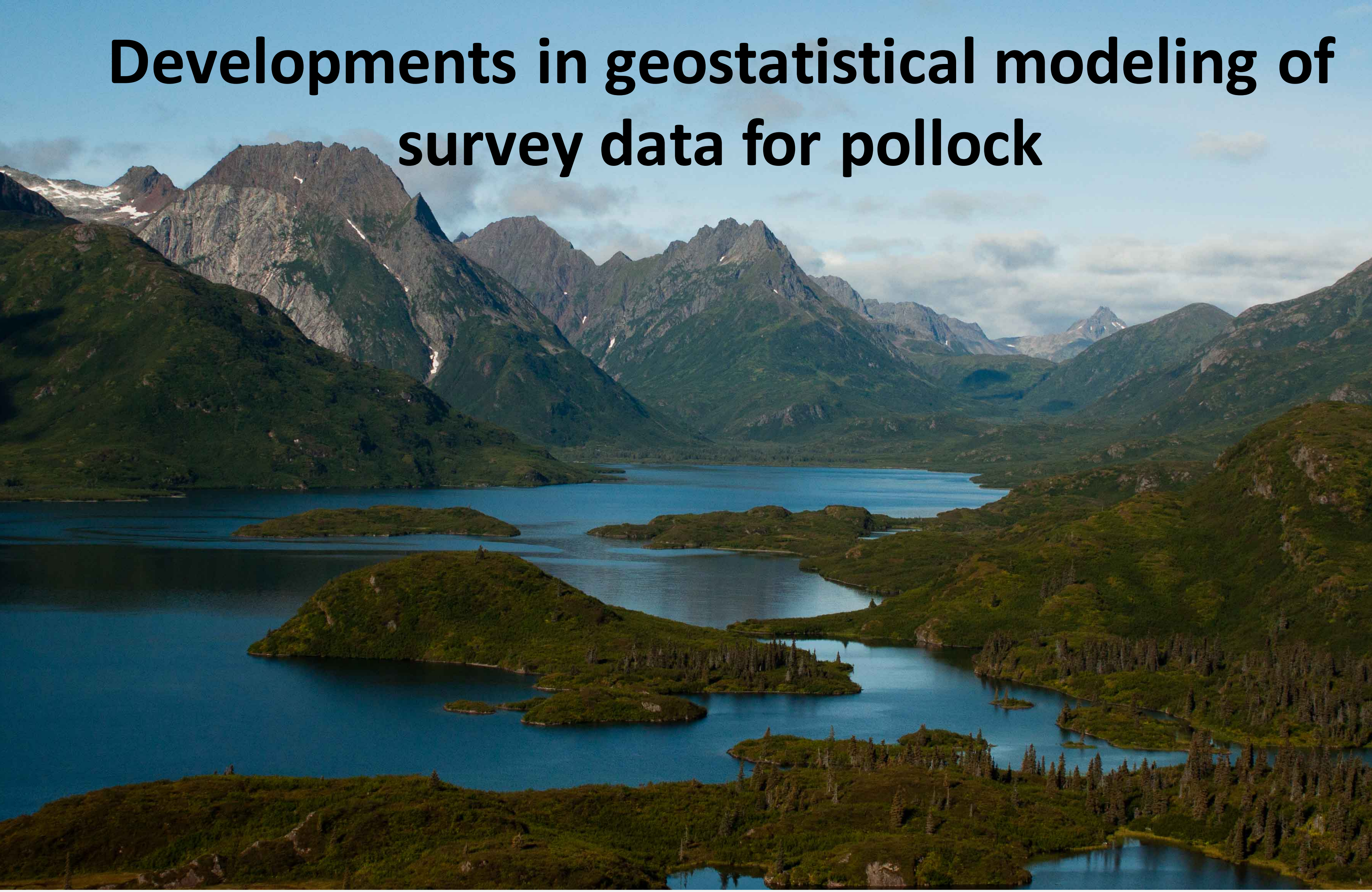
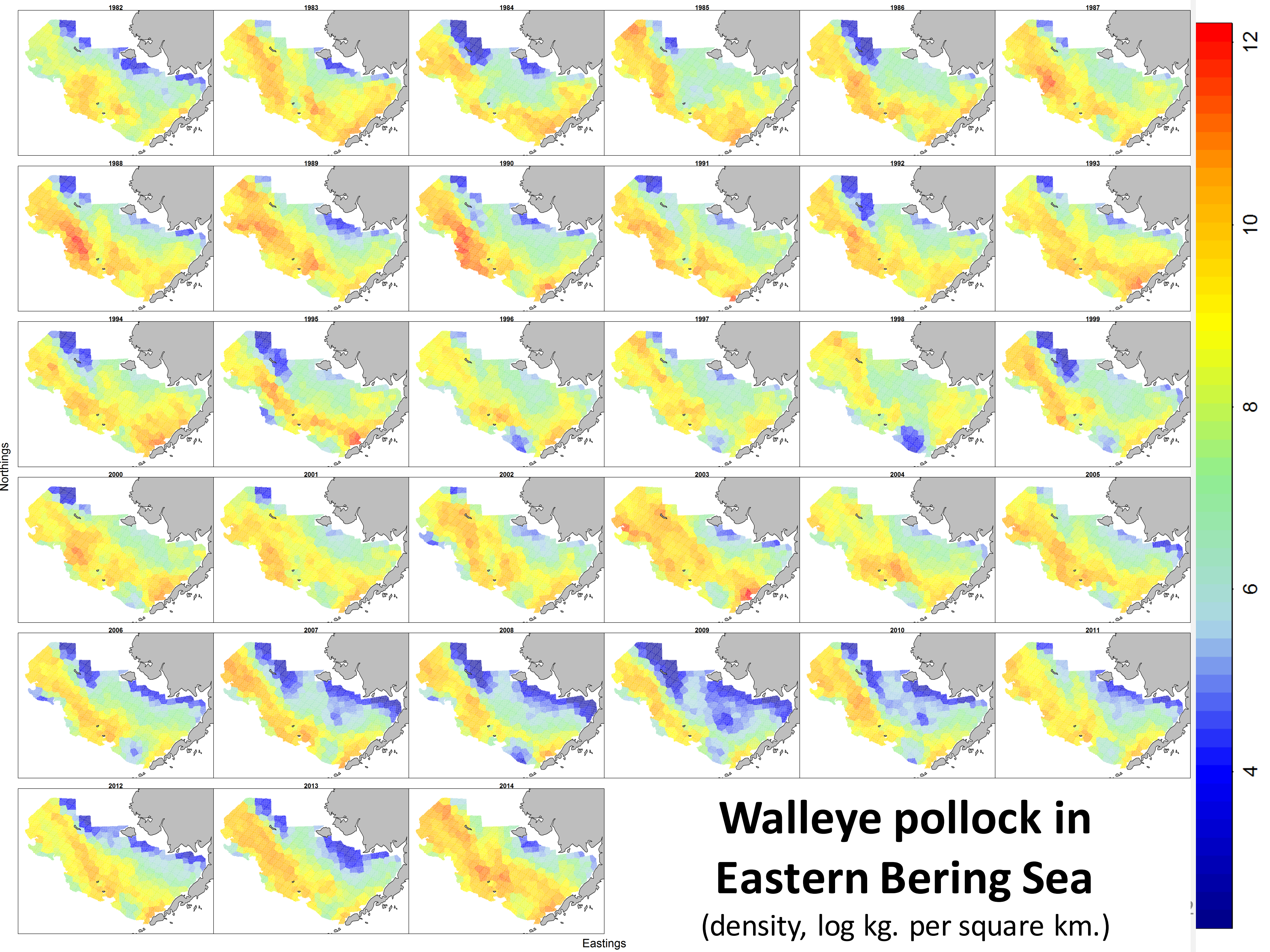
Developments in geostatistical modeling of survey data for pollock



Thorson, J.T., Ianelli, J.N., Larsen, E., Ries, L., Scheuerell, M.D., Szuwalski, C. & Zipkin, E. (In press) Joint dynamic species distribution models: a tool for community ordination and spatiotemporal monitoring. *Global Ecology and Biogeography*.


1982
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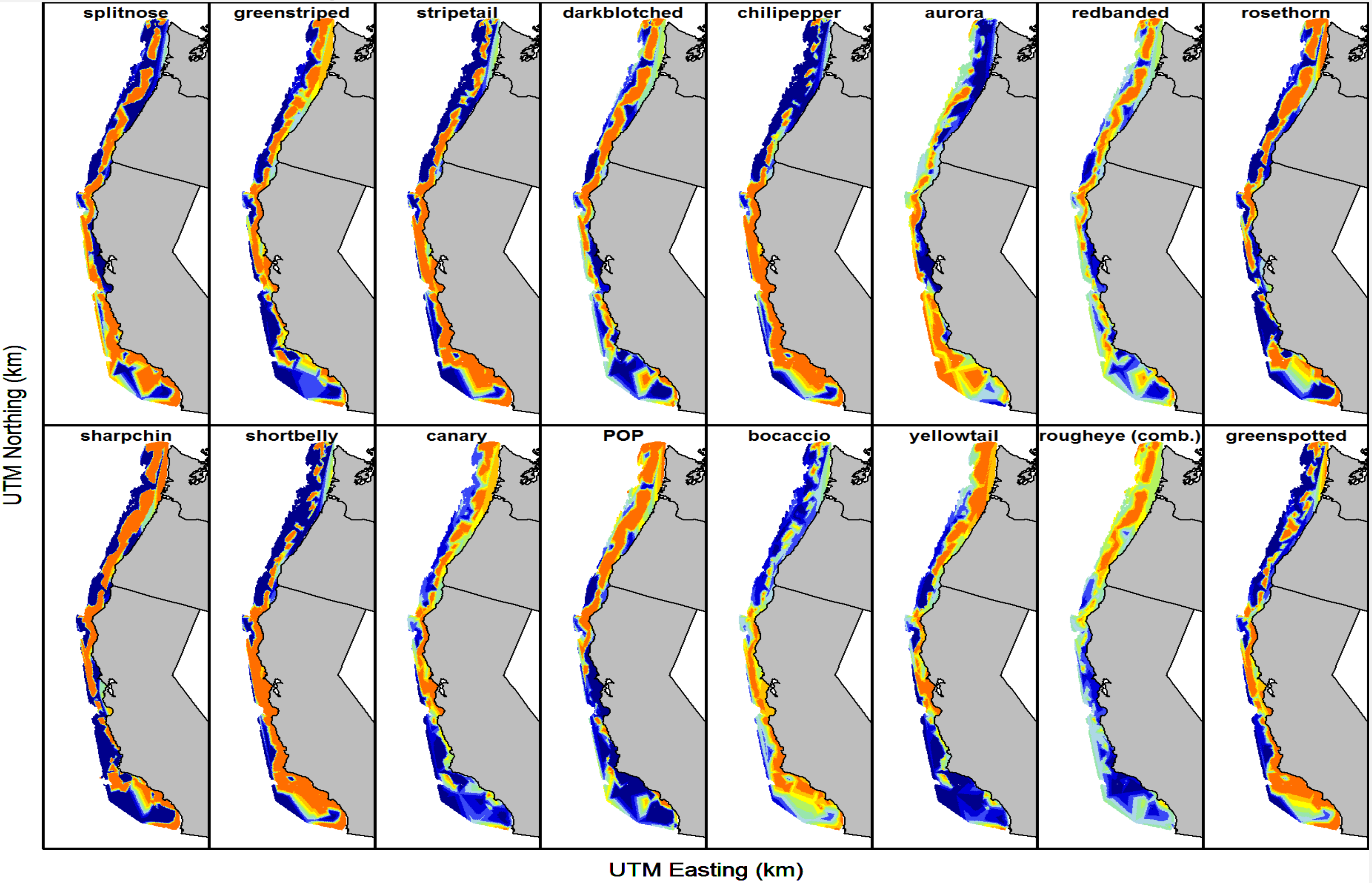
2009
2010
2011
2012
2013
2014
Northings
Eastings
12
10
8
6
4
Walleye pollock in
Eastern Bering Sea
(density, log kg. per square km.)

Joint species distribution models



Thorson, J.T., Scheuerell, M., Shelton, A.O., See, K., Skaug, H.J., Kristensen, K., In press. Spatial factor analysis: a new tool for estimating joint species distributions and correlations in species range. Methods in Ecology and Evolution

Joint species distribution models

Spatial factor analysis

- Estimates *K* "latent" maps for co-occurring species
- Separates process and measurement error
- Derived estimates of co-occurrence

Multispecies catches

$$c_p(s) \sim \mathrm{Poisson}\big(\exp(\lambda_p(s))\big)$$

Expected densities

$$\lambda_p(s) = \alpha_p + \sum_{k=1}^{K} L_{p,k}\omega_k(s)$$

Where:

- $\omega_{i,k}$ is the *k*-th factor
- $L_{p,k}$ is the loadings for factor *k on* species *p*
- α_p is an intercept for species *p*
- $\lambda_{i,p}$ is predicted log-density for species *p* at location *i*

Spatial Gompertz model

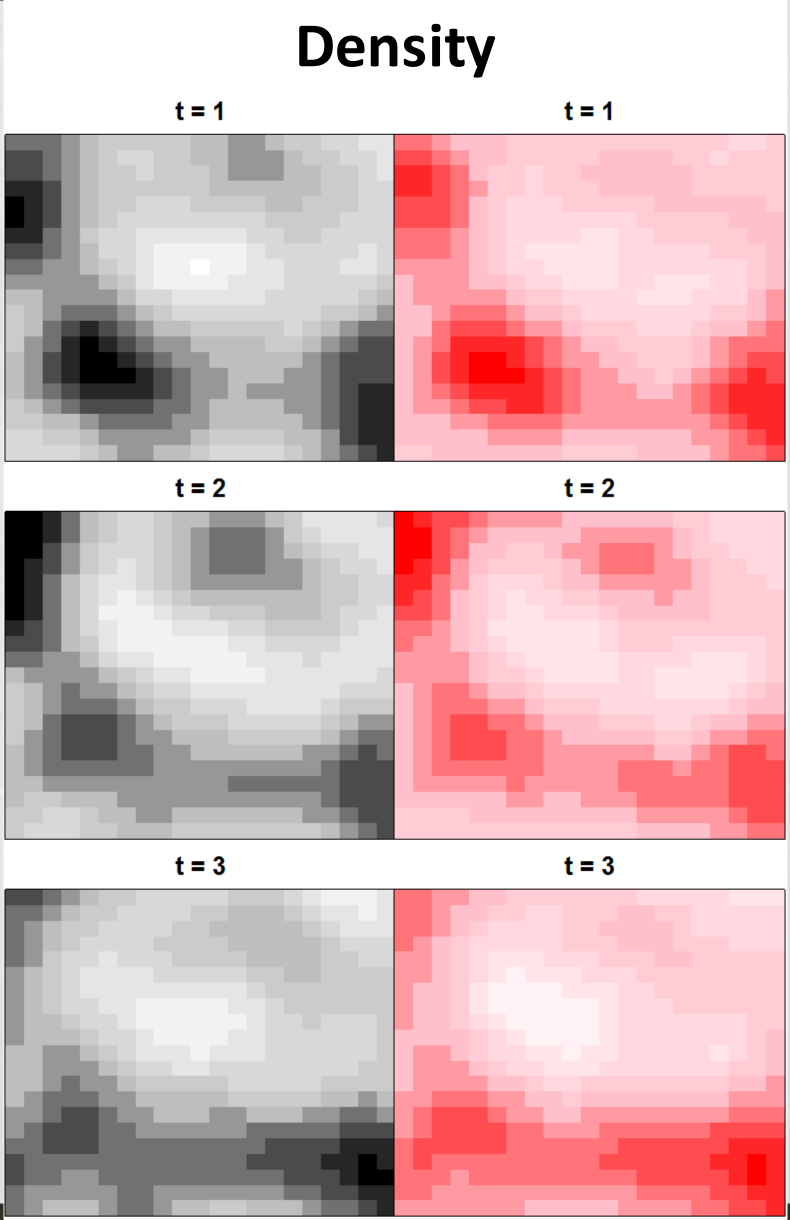
Autoregressive model

$$\log(\mathbf{d}_{t+1}) = \rho \log(\mathbf{d}_t) + \boldsymbol{\omega} + \boldsymbol{\varepsilon}_t$$

$$c_i \sim \text{Poisson}\left(d_{t(i)}(s_i)\right)$$

Where

- ρ is the strength of density dependence
- $\boldsymbol{\omega} \sim \text{GMRF}(\boldsymbol{\alpha}, \boldsymbol{\Sigma}_\omega)$ is spatial variation in carrying capacity
- $\boldsymbol{\varepsilon}_t \sim \text{GMRF}(\mathbf{0}, \boldsymbol{\Sigma}_\varepsilon)$ is spatiotemporal variation



Joint species distribution models

Model structure

- Factors follow Gompertz dynamics

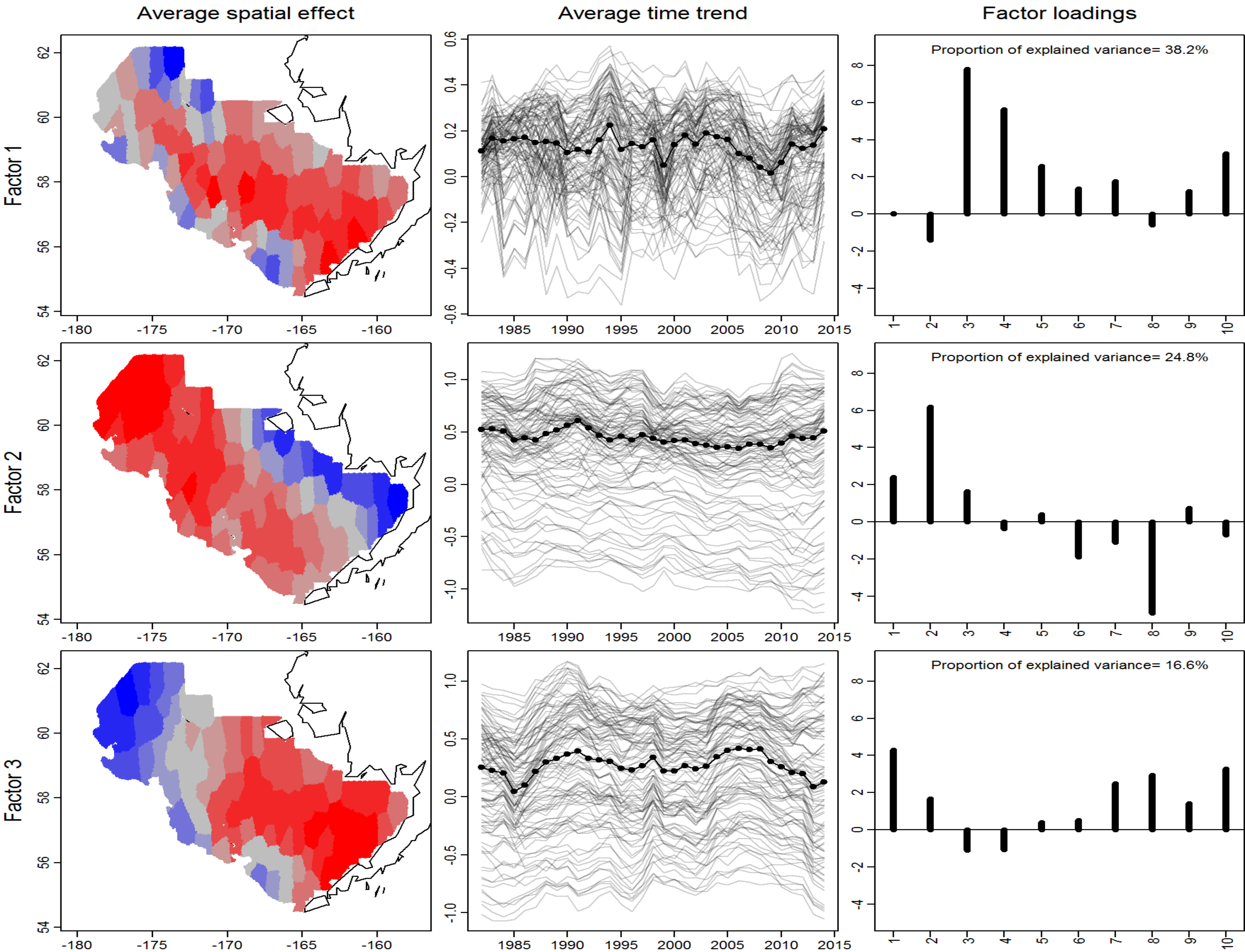
$$\log\left(\mathbf{d}_{t+1,k}\right) = \rho \log\left(\mathbf{d}_{t,k}\right) + \boldsymbol{\omega}_k + \boldsymbol{\varepsilon}_{t,k}$$

- Density is log-linear combination of factors

$$\lambda_{t,p}(s) = \alpha_p + \sum_{k=1}^{n_k} L_{p,k} \log\left(d_{t,k}(s)\right)$$

- Data follow a standard count process

$$c_{i,p} \sim \mathrm{Poisson}\left(\lambda_{t(i),p}(s_i)\right)$$


Average spatial effect
Average time trend
Factor loadings
Factor 1
Factor 2
Factor 3
Proportion of explained variance= 38.2%
Proportion of explained variance= 24.8%
Proportion of explained variance= 16.6%

Joint species distribution models

Conclusions

- Can reconstruct community dynamics
- Phylogenetic signal in species correlations
- Can identify “spatial scale” of community dynamics

Common Name	Species number	1	2	3	4	5	6	7	8	9	10
Tanner crab	1	1.000	0.454	0.049	-0.166	0.218	-0.176	0.047	0.067	-0.108	0.364
snow crab	2		1.000	-0.086	-0.277	-0.035	-0.411	-0.148	-0.638	0.356	-0.065
walleye pollock	3			1.000	0.910	0.505	0.130	0.227	-0.333	0.150	0.504
Pacific cod	4				1.000	0.592	0.502	0.196	-0.129	0.244	0.523
flathead sole	5					1.000	0.429	0.206	-0.068	0.271	0.153
Pacific halibut	6						1.000	0.041	0.522	0.251	0.441
yellowfin sole	7							1.000	0.346	0.649	0.510
starry flounder	8								1.000	-0.073	0.381
Alaska plaice	9									1.000	0.380
sturgeon poacher	10										1.000

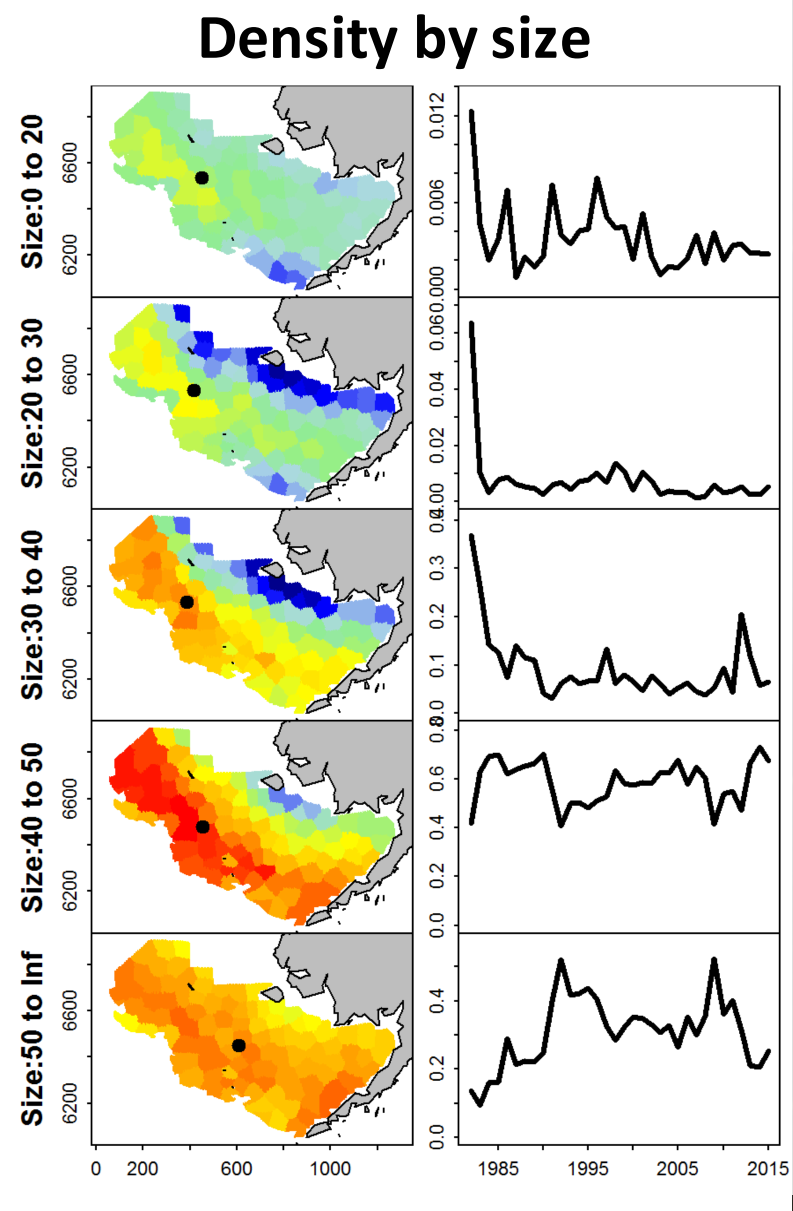
Temperature impacts on pollock

Thorson, J.T., Kotwicki, S, Ianelli, J.N. (In prep) The relative influence of temperature on fish distribution shifts: An important metric for forecasting future climate impacts.

Temperature impacts on pollock

VAST model

- Vector-Autoregressive Spatio-Temporal model
- Model density for every time, place, and size-class
  - Correlations over space for each size-bin
  - Correlations among size-bins for every year
- Includes temperature effects
  - Quadratic surface temperature
  - Quadratic bottom temperature
  - Regional temperature effect
    - Cold pool area interaction with location north-south or east-west



Temperature impacts on pollock

Derived quantities

$$d(s,t) = \exp(\lambda(s,t))$$

1. Total abundance

$$B(t) = \sum_{s=1}^{n_s} d(s,t) \times a(s)$$

2. Center of gravity

$$\bar{x}_t = \frac{1}{\sum_{s=1}^{n_s} (d(s,t) \times a(s))} \sum_{s=1}^{n_s} x(s)(d(s,t) \times a(s))$$

3. Average density

$$\bar{d}(t) = \frac{1}{\sum_{s=1}^{n_s} (d(s,t) \times a(s))} \sum_{s=1}^{n_s} d(s,t)(d(s,t) \times a(s))$$

Temperature impacts on pollock

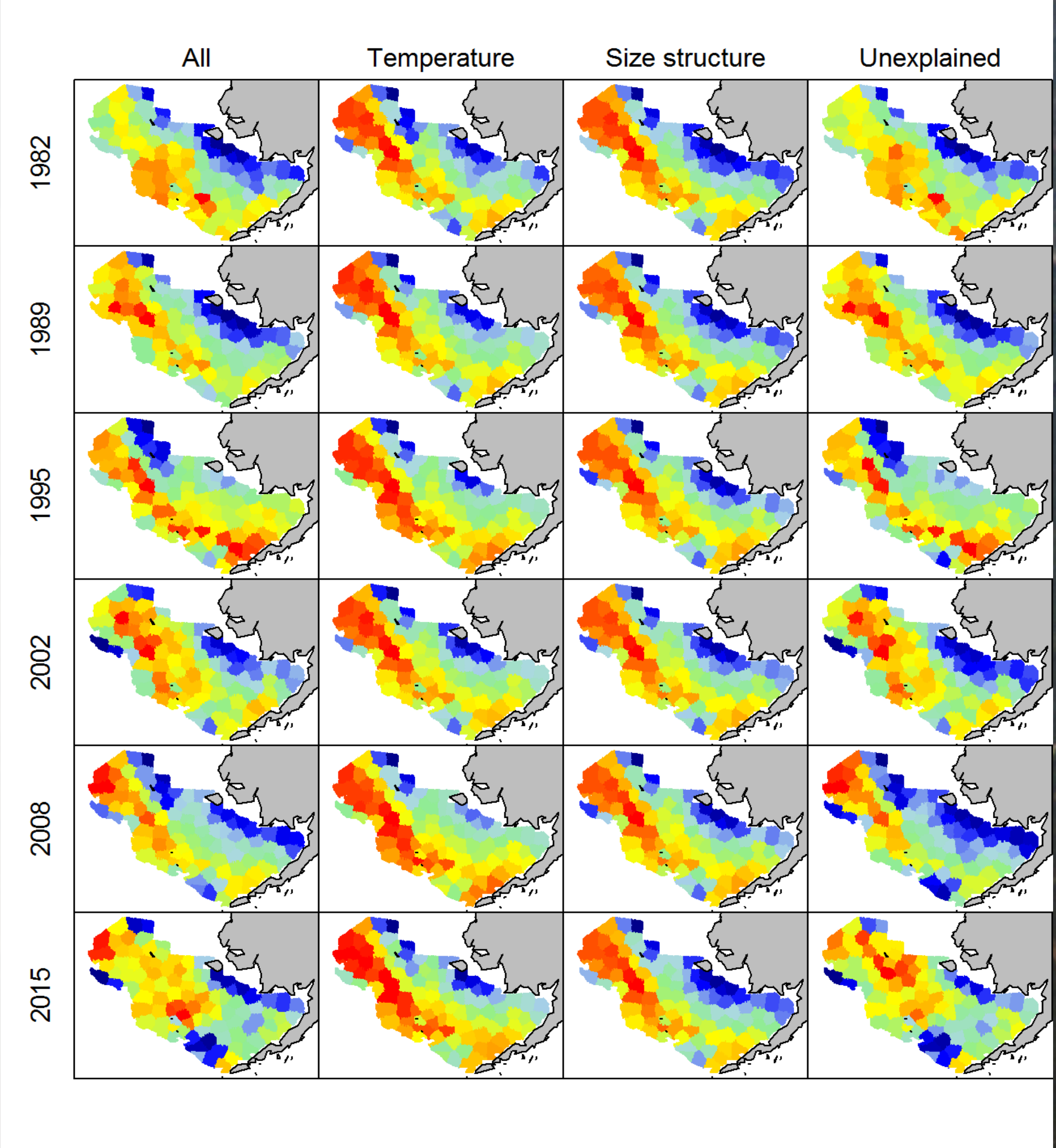
Three counter-factuals

1. Just temperature effects
   - Turn off spatio-temporal variation
   - Turn of variation in size-structure over time
2. Just “recruitment-variation” effects
   - Turn off temperature effects
   - Turn off spatio-temporal variation
3. Just residual variation
   - Turn off temperature effects
   - Turn off variation in size-structure over time

Temperature impacts on pollock

Distribution for all counter-factuals

- Most observed variation is in the “unexplained” counter-factual



Temperature impacts on pollock

Distribution for all counter-factuals

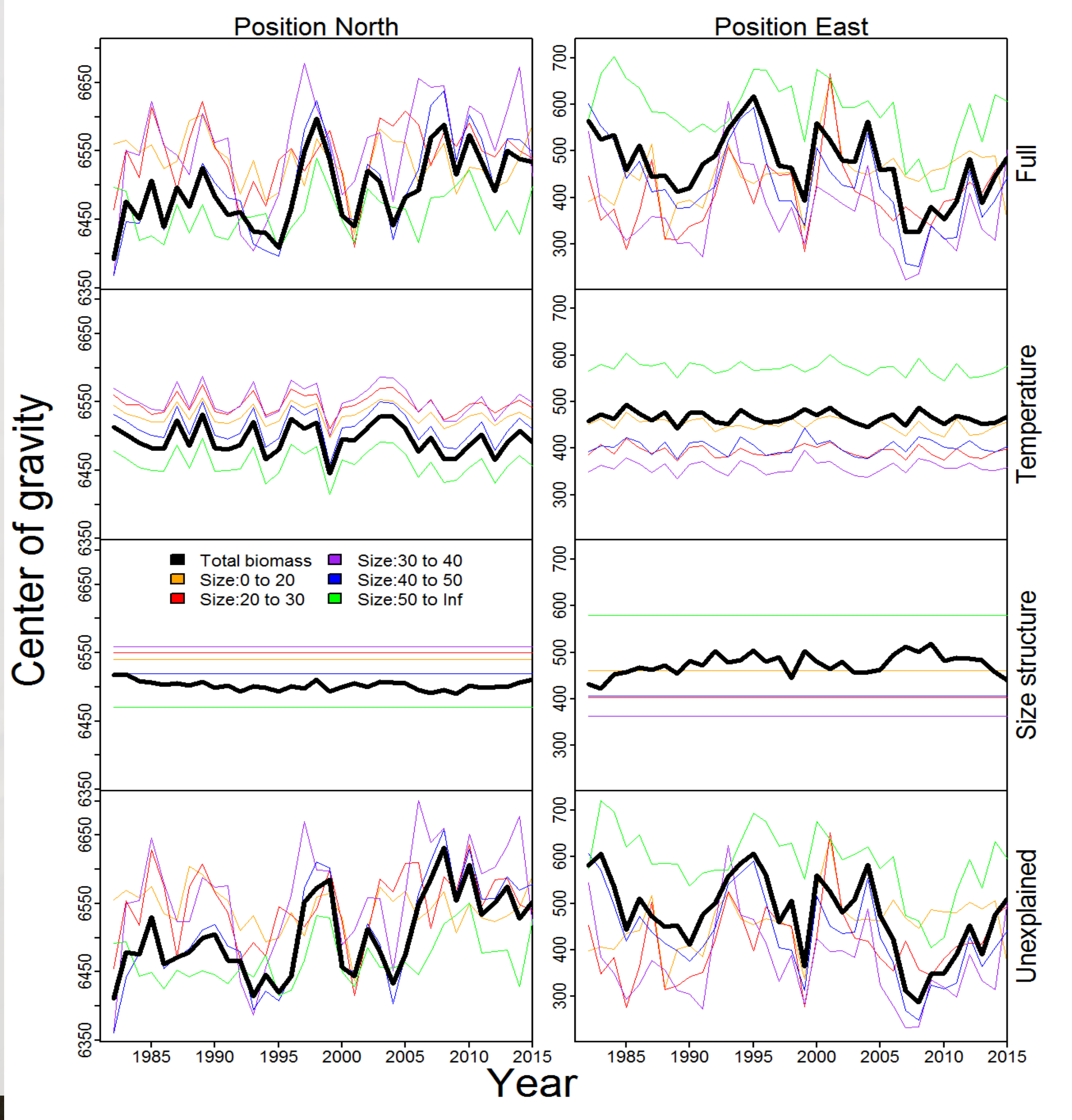
- Temperature generates some north-south variation
- Recruitment generates some east-west variation

	Northings COG (kilometres)	Eastings COG (kilometres)
Abundance weighted average estimator	44.6	70.4
Full model	51.5	74.0
Only temperature	21.5	12.8
Only recruitment-variation	6.8	22.7
Only unexplained	58.9	84.0

Temperature impacts on pollock

Distribution over time

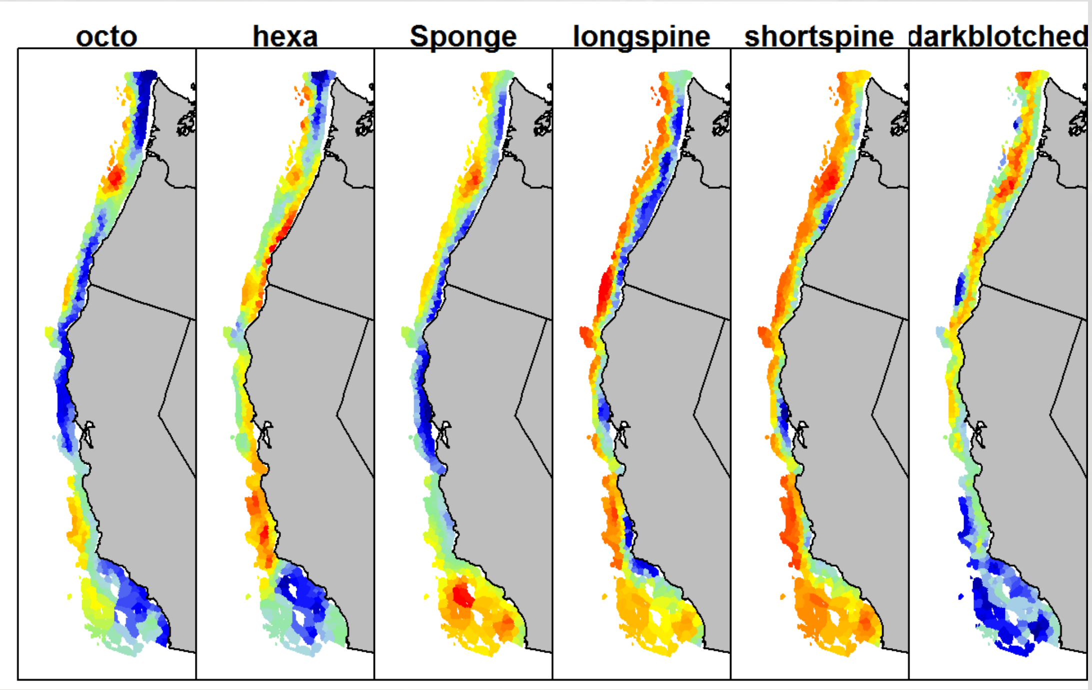
- Trend north and west over time
- Neither temperature of size-structure captures the trend



Discussion

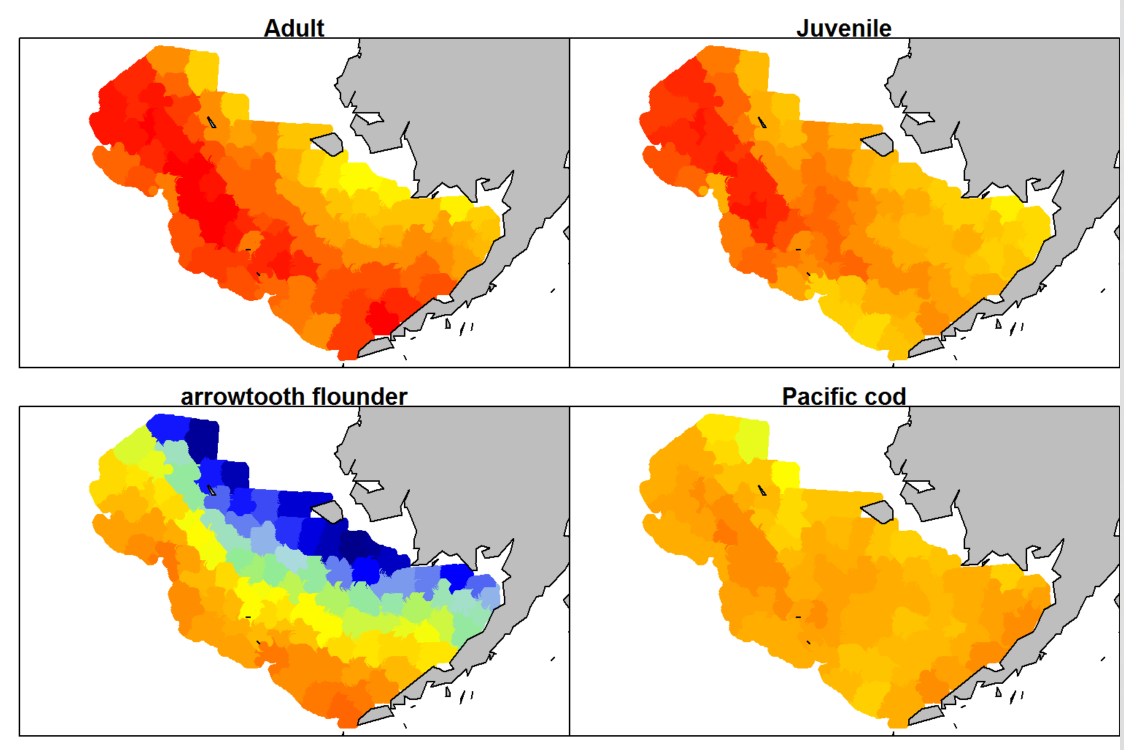
Future directions

1. Spatial ecosystem-based management
   - Estimate associations between fish and habitat



Future directions

2. Spatial predator-prey overlap
   – Estimate associations between fish and habitat



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